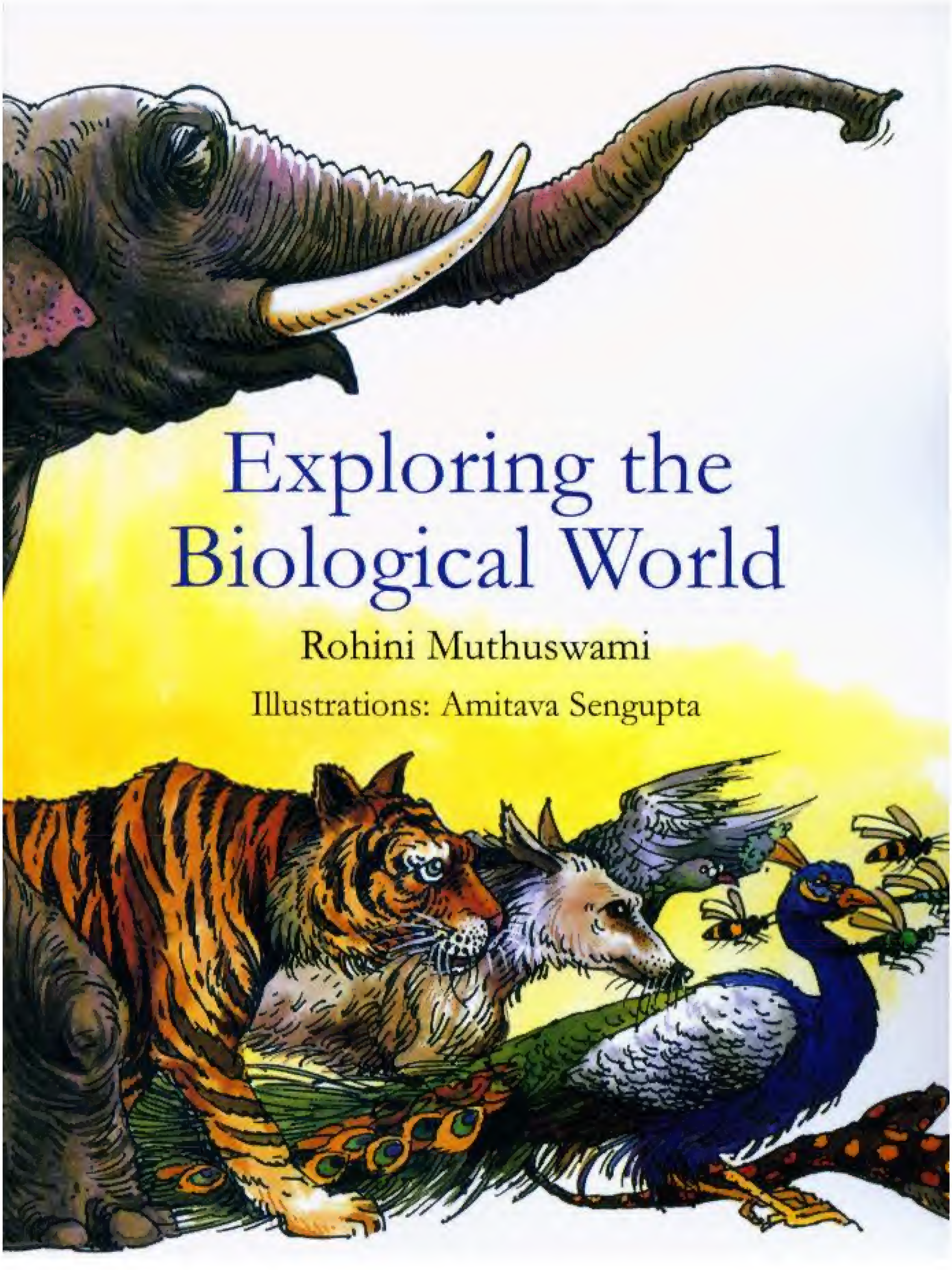

Exploring the Biological World

Rohini Muthuswami

Illustrations: Amitava Sengupta

Creative Learning Series

EXPLORING THE BIOLOGICAL WORLD

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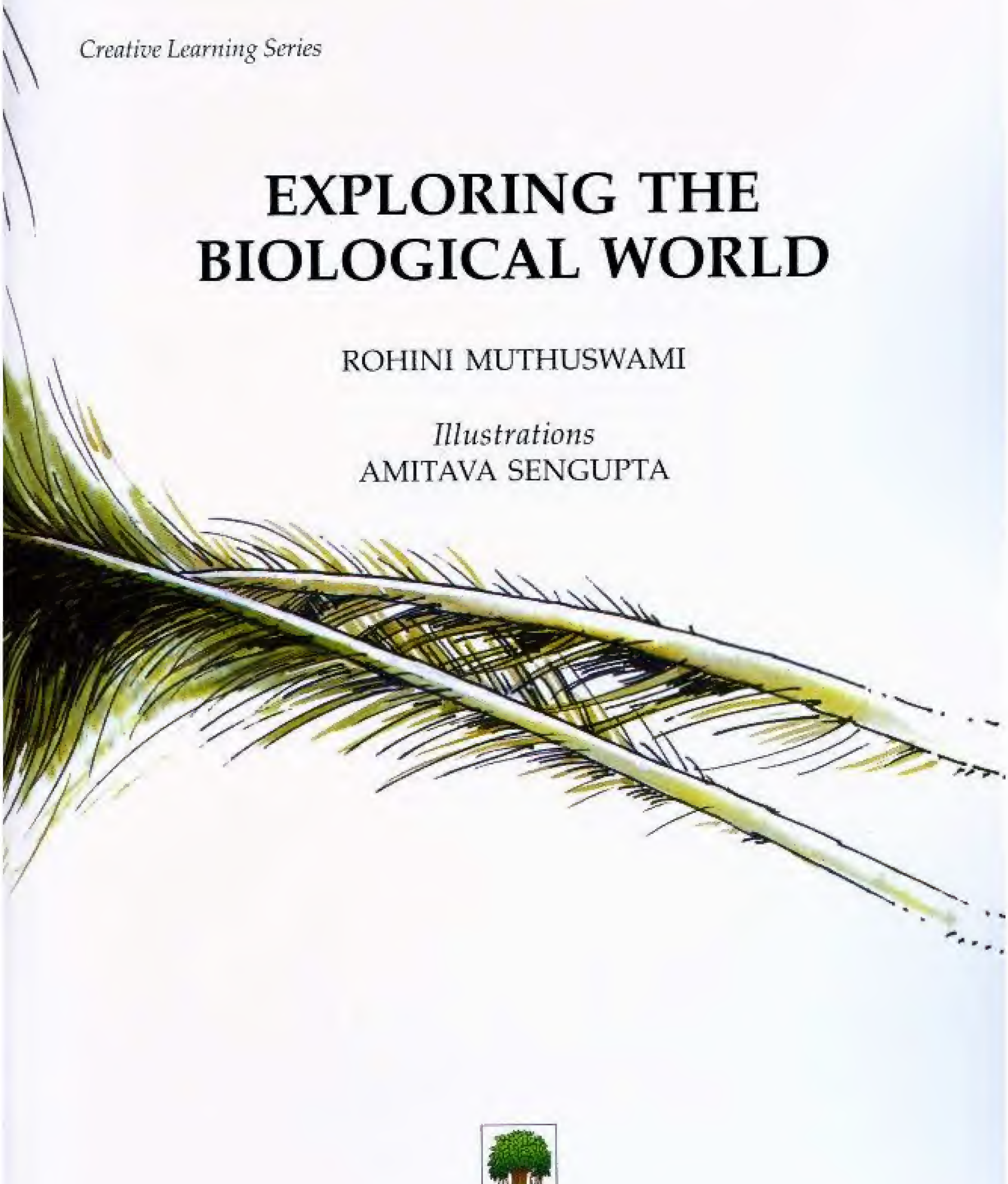

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Contents

The Mathematics of the Honeycomb

How doth the little busy bee
Improve each shining hour,
And gather honey all the day
From every opening flower!

How skillfully she builds her cell!
How neat she spreads the wax!
And labours hard to store it well
With the sweet food she makes!

— ISSAC WATTS

My laboratory was getting white washed from the outside. The cleaners had knocked the empty honeycomb out from the wall. It lay on the floor, face upward, hexagonal cells lying symmetrically with no empty space between them.

For a minute I stared at it wondering why bees used a hexagonal cell. It was a beautiful honeycomb but do bees really construct a hexagonal cell for its beauty? Why did bees evolve this structure for the honeycomb?

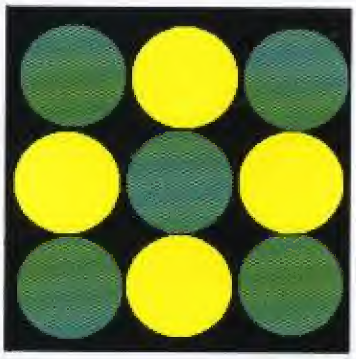
It is a question that has been puzzling mankind since the times of the Ancient Greeks.

The honeybee, it turns out, is a master engineer. Charles Darwin described the honeycomb as "beyond this stage of perfection in architecture natural selection could not lead; for the comb of the hive-bee, as far as we can see, is absolutely perfect in economizing labour and wax."

Let us look through some of the mathematical shapes:

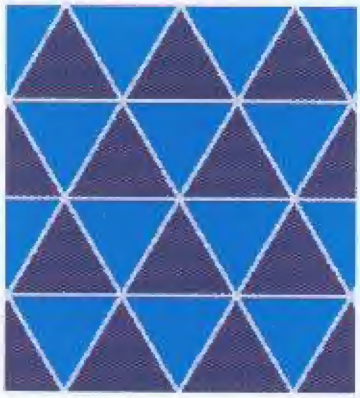
If the honeybee used a circular shape, it would result in a beehive with holes between adjacent cells:

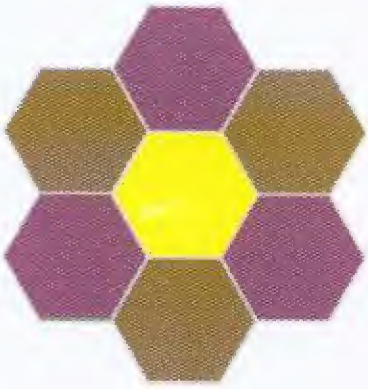
Of all the shapes possible, only three fit perfectly with no space between the cells. Mathematicians call this phenomenon tessellation.



The geometric shapes that tessellate are triangle, square, and hexagon:

If we consider a triangle, a square, and a hexagon, each having a perimeter of 1 centimeter, then we can calculate the area of each one as follows:





Equilateral Triangle

Each side = 1/3 centimeter

Area of the triangle = $\sqrt{3}/4 \times 1/3$ (centimeter) x 1/3 (centimeter) = 0.048 (square centimeter) ^{2}

Square

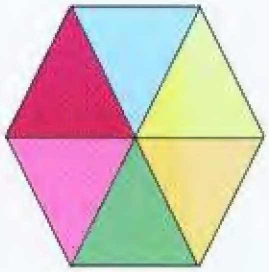
Each side = 1/4

Area of the square = 1/4 (centimeter) x 1/4 (centimeter) = 0.0625 (square centimeter)^2

Regular Hexagon

Each side = 1/6

We can consider a regular hexagon as though it is made of 6 equilateral triangles:



Therefore, the area of the hexagon can be described as = $6 \times \sqrt{3}/4 \times 1/6$ (centimeter) x 1/6 (centimeter) = 0.072 (square centimeter).

Thus, we can now see that of the three shapes, the hexagon has the maximum area, and thus can store maximum amount of honey.

I picked up the honeycomb from the floor. It lay on my hand, light and papery; a puff of wind would blow it away. A honeycomb weighs only few ounces. And that is another secret of using a hexagonal cell! Remember, Charles Darwin said that the honeycomb economizes on wax. So it turns out that: A hexagonal honeycomb uses the least amount of wax; the triangular cell would need 18% more wax and a square cell would need 7% more wax.

A honeycomb is a thin-walled double-layered structure with hexagonal cells laid back to back. It is made of bees wax, secreted by the worker bees, and propolis, a resin that the bees collect from plants.

Young workers secrete wax from wax glands that are located on the underside of their abdomen when they are 10-12 days old. They chew on it and this chewed up wax is used for building the honeycomb cells. The wax hardens when formed into the cell walls of the comb.

This wax can be taken out and melted; it melts over 60ºC, it is made of at least 284 different compounds. The major ones are: alkanes, acids, esters, polyesters and hydroxyesters.

Propolis is a brown coloured resin that bees obtain from the buds of the trees; they use it to cover any cracks in the hive.

The hexagonal cells are precisely placed. Edwin Way in his book 'The Golden Throng' explains it thus:

> An instance, which illustrates this fact, was related to me by a New York die-maker. Sometime ago he was commissioned to produce a zinc die for pressing honeycomb into the foundation used in beehives. The die was completed; the comb foundation made. Then

> it was discovered the bees refused to use them. A check up revealed that the workman who laid out the die had been off on his cell dimensions, a tiny fraction of an inch. When the die was redesigned and the error eliminated, the insects accepted the new foundations and built their cells upon them.

As mentioned earlier, the honeycomb consists of cells placed back to back. The cells are tilted upwards at a 13º angle; just enough to make sure that the stored honey does not spill out.

Is the hexagon the optimum shape? Mathematicians think it is not. In the article in American Scientist, March-April 2000, Erica Klarreich in her article 'Foams and Honeycombs', says that the three-dimensional honeycomb partition is not optimal. Each cell is a hexagonal prism capped off on one end by three rhombi, but substituting a truncated octahedron would produce a small saving. The full honeycomb consists of two layers of these cells, stacked together so that the caps of one layer fit into the gaps of another, like a jigsaw puzzle, and has characteristics more like wet foam than dry foam. And in fact when dry foam with the optimal octahedron configuration has liquid added to it, the structure suddenly switches to the bees' configuration.

So in the end it seems the bees got it right!

How did bees evolve into such master engineers? Did they experiment with various shapes before they hit upon the hexagon? Were there bees that had made hives using triangular or square shapes?

I do not know the answers to the questions milling in my head.

It is my brother's favourite maxim that there is mathematics in everything; this is the first time I have such a wonderful proof for it.

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The Plumes of the Peacock

With pendant train and rustling wings,
Aloft the gorgeous peacock springs;
And he, the bird of hundred eyes,
Whose plumes the dames of Ava prize.

—BISHOP HEBER

The peacock is perched on the edge of the roof, all his feathers spread out, and showing off his beauty to the unimpressed peahen grazing nearby. The neck is an iridescent blue; the feather a mesh of blue, green, and brown, with intricate eye patterns, and on the top of his head is a silly little crown.

A bird can obtain its characteristic colour through pigments, same like the way carrots are red and our skin is brown. These pigments are mainly of the type:

Melanin—the pigment that gives colour to our skin—which shades the feather brown, black or grey

Carotenoids—the pigment that gives carrot its colour—which makes the feather red or yellow

Porphyrins, which shades the feather red, brown and green.

But, many birds, especially the ones that are blue, white, or iridescent, obtain their colour because of quirks in the structure of the feather.

A feather is made of 91% protein, 1.3 % fat, and 7.9% water. It has a central shaft which is made of a hollow shaft base called calamus or quill and a rachis that supports the vane. A vane is the functional feather that arises from each side of the rachis.

A vane is made of barbs that are primary branches off the rachis. Each barb has a tiny branch that can be observed only under the microscope. These tiny branches are known as barbules. Each barbule has a hook like structure that zips the barbs together. This hook is known as barbicle or hamuli.

Visible light, as we all know, is made of colours of light each with a unique wavelength. The red light is long with a wavelength of 700 nm and the blue light is the shortest with 400 nm wavelength.

The colour we see depends upon the object. Some objects absorb all the colours and reflect very little back. Such objects will appear black. Others absorb none and reflect back all the light falling on them. These objects will appear white. A leaf appears green because chlorophyll, a pigment present in the leaves, absorbs all colours and reflects out only green. It has reflected back green colour which is perceived by our eyes and hence the leaves appear as green coloured. Such an object will appear green no matter which angle you look from. That is why our skin appears a uniform brown.

But not so with iridescence. Look at the common pigeon, which we call *kabutar* in Hindi. Its body is grey but its neck is bejewelled green and magenta. If you look at its neck from different angles, different colours will appear.

As far back as 1704 in his book *Opticks* Sir Isaac Newton proposed that iridescence is created by interference of light.

Let us take a look at a soap bubble. It shimmers and glimmers as we change the angle of observation.

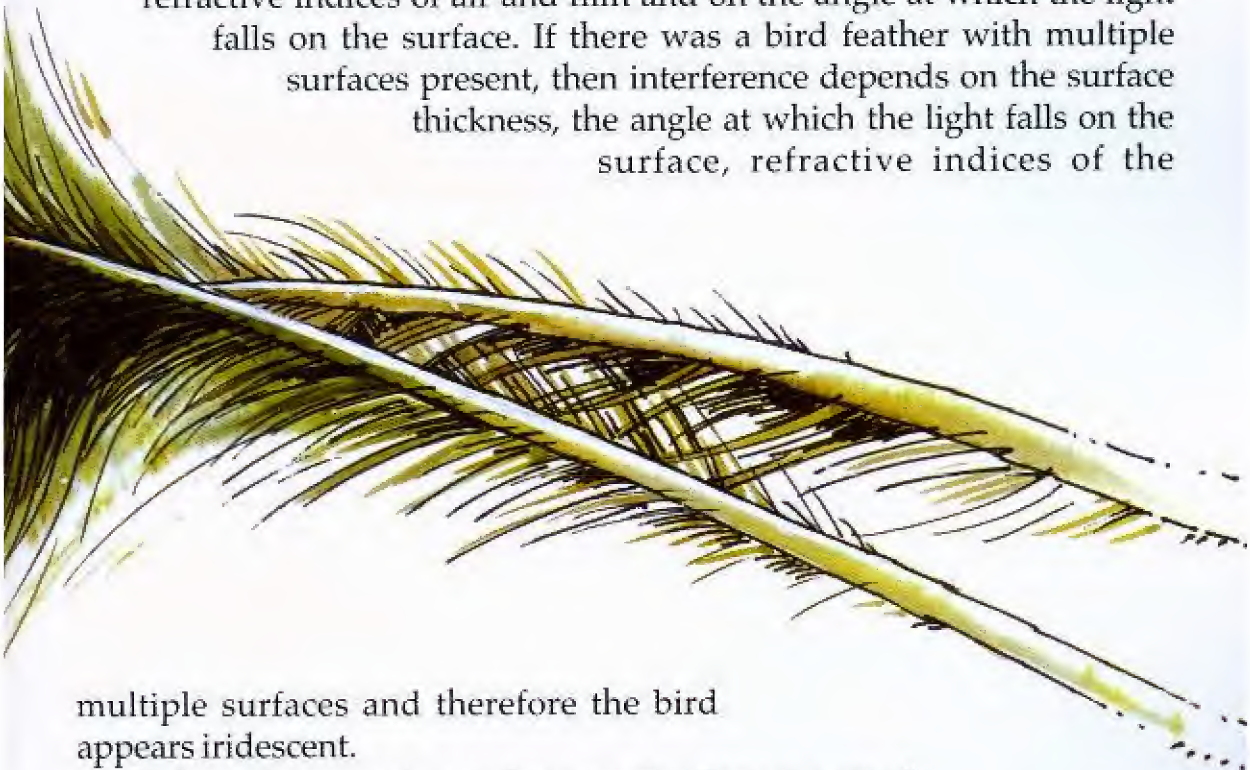
When light falls on the soap bubble, it meets the first surface. Some of the light is reflected right back. The remaining enters the film and travels till it meets the second surface.

When it meets the second surface, it can also be sent back. So you have now two reflected light travelling back. When they meet, two things can happen:

They can be in phase; that is the valley can match with valley and the crest with the crest. The two waves will add up and the phenomenon is known as constructive interference.

They can be out of phase; that is the valley meets the crest and they cancel out. The phenomenon is known as destructive interference.

For a soap bubble with just two surfaces, interference depends on refractive indices of air and film and on the angle at which the light falls on the surface. If there was a bird feather with multiple surfaces present, then interference depends on the surface thickness, the angle at which the light falls on the surface, refractive indices of the



multiple surfaces and therefore the bird appears iridescent.

So how do peacocks get their spectacular colouring?

Jian Zi, a scientist at Fudan University, Shangai, China, returned home one day from the market place with a bunch of peacock feathers. Fascinated by the beauty of the peacock feather, he put them under the microscope to discover what caused the brilliance. He found that the bright colours present on the peacock are produced by tiny, two-dimensional crystal like photonic structures present in the barbules of the feathers. They looked at the blue,

green, yellow and the brown barbules and found that the spacing between the photonic structures differed in these barbules. Then they calculated the interference of light that is reflected from the front of the structure and the light that is reflected from the back of the structure before emerging from the front, just like in the soap bubble.

Photonic crystals are made in laboratories too. These crystals are used in a number of optical devices ranging from lasers to extremely miniaturized light switches and light guides.

The ones found in the peacock are not as perfect as the ones made in the lab. But these crystals were created without use of harsh chemicals or expensive materials and were assembled without expending a great deal of energy and operate at normal temperature and pressure. Can we adapt these structures for our use?

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The Spider Web

A noiseless patient spider,
I mark'd where on a little promontory it stood isolated,
Mark'd how to explore the vacant vast surrounding,
It launch'd forth filament, filament, filament, out of itself,
Ever unreeling them, ever tirelessly speeding them.

— WALT WHITMAN

One of the most hateful jobs around the house is the removal of spider webs. The web, dirty and sticky, collapses on the broom and then I take it out and shake off the icky thing. Yuck!

But hey, wait a minute! How come it does not collapse when a fly walks into the parlour on the spider's invitation? And how come the spider does not get stuck within its sticky web?

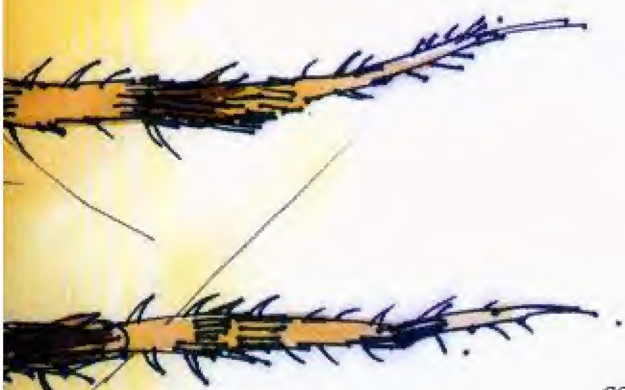
Remember the movie Spider Man where with a motion of his hand he spins out a web? That is what the spider does. But its web is not so thick. It need not be for the spider makes one of the strongest silk known to man.

Spiders make silks for many different purposes: making the web, making a cocoon, for travelling, for wrapping up the prey.

Silk is made of a protein called fibroin. Proteins are made of chemical blocks called amino acids. Each amino acid is made of carbon, hydrogen, nitrogen, and oxygen. Two amino acids are joined by a peptide bond. A series of amino acids joined together forms a polypeptide, which is ultimately folded to form a protein which can perform a specific function. In case of spider silk, the function of the silk protein is to provide high tensile strength and elasticity so that the web can withstand the impact of a captured prey.

Spider silk is made in silk glands present in the abdomen of the spider. There are seven different types of silk glands each producing silk with specific properties. However, no spider is known with all seven different types of glands.

The silk comes out through spigots, which are mobile finger-like protrusions. The diameter of a single fibre is controlled by the muscular action of a valve. The faster and tighter the strand is drawn, the stronger the silk. Silk is not ejected under pressure, so it is not that the spider kind of pushes out the silk. Instead, the spider attaches the silk thread to a surface and then starts walking away, the silk comes out of the spigots as she does so.



The toughest silk is the dragline silk which has the tensile strength of steel, which is amazing considering that with a sweep of broom it can be wiped away. The dragline silk is used to make the frame and the spoke (radial) lines of the web.

The spirals are made of spiral line silk which is much weaker than the dragline silk but very, very stretchy—it can stretch up to 200%—and very, very sticky. This is the part where the insect gets caught.

Araneus didimata, the orb-weaving spider, begins its web from the centre called the hub. This is surrounded by free zone, where the spider can move freely. Radial lines, which are also dry fibres, connect the hub to the outer frame. Spiral threads are then laid down; these go from the outside of the free zone to the edge of the frame. Finally sticky threads coated with sticky droplets are laid down from outside to the free zone. The spider waits in the centre till an insect happens to carelessly walk into the web; then she wraps it up and paralyzes the hapless prey.

So we come back to the question: why does not a spider get caught within its own web?

The legs of the spiders possess some sort of a disengaging mechanism by which it can shake its legs free when walking on a sticky

surface. Each leg ends with a pair of walking claws that is necessary to get a good grip on a smooth surface. In front of the walking claw is a hooked third claw. This third claw helps in getting rid of the silk strand when the spider walks on the sticky surface of the web.

Fibroin contains very high contents of two particular amino acids. One is called glycine and the other is called alanine. The dragline silk contains multiple repeats 8-10 residue long of poly-alanine block and a 24-35 residue long glycine-rich block. When fibroin is spun into fibres, the poly-alanine blocks form crystals that can cross-link the protein into a polymer network that possess high degree of stiffness coupled with strength, and toughness.

If we compare the dragline silk with man-made carbon fibre which is used for transmitting and supporting tensile forces, we find that the dragline

silk has much lower stiffness but much higher extensibility than the carbon fibre. Consequently, its toughness is much higher than the carbon fibre, and does not break when the prey is caught within the mesh.

The incredible lightness, toughness, and extensibility—is it the fibre of the future?

Interesting Links:

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The Stripes of the Tiger

Tiger! Tiger! Burning bright,
In the forests of the night,
What immortal hand or eye
Could frame thy fearful symmetry?

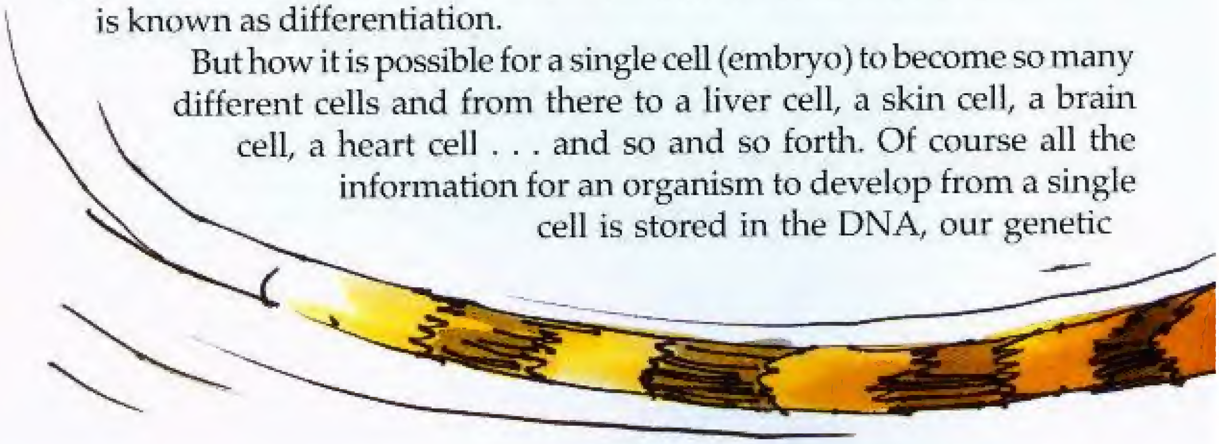
— WILLIAM BLAKE

Tigers are fast disappearing from our forests. How many are really left? How do we count them? One of the ways to count the number of tigers in a forest is to photograph each one of them and to study the stripe pattern. Just like our fingerprints (no two fingerprints are same) or like the snowflakes (no two snowflakes are identical) each tiger has a unique stripe pattern.

But how do the stripes on a tiger arise? Or the spots on a leopard or the zigzag lines of a zebra, the spots of the giraffe? Is the information for making stripes written in the DNA, the store house of all genetical material? Or are there some other factors at work there?

Alan Turing was a mathematician and the founder of modern computer science. Some time in 1950s he was puzzled by the development of an embryo into a full adult. As we all know, we start our lives as a single cell. Division upon division finally results in a full-formed individual. When a cell decided to become a liver cell and proceeds down that path, the process is known as differentiation.

But how it is possible for a single cell (embryo) to become so many different cells and from there to a liver cell, a skin cell, a brain cell, a heart cell . . . and so and so forth. Of course all the information for an organism to develop from a single cell is stored in the DNA, our genetic



material. The problem is that of a symmetrical single cell becoming asymmetrical such that when it divides into two unequal cells, that is for example one cell becomes heart cell and the other becomes a liver cell. Somehow differences have crept into that one single cell so that when it divides, the two daughter cells are no longer equal. How did it come about?

This was the problem that Alan Turning was interested in. The model he proposed is called as reaction-diffusion process. We will try to understand this model through the tiger stripes.

The stripes of the tiger are brown in colour. As we talked about in the Plumes of the Peacock, the brown colour is due to the pigment called melanin. Cells that can produce melanin are called as differentiated cells or melanocytes (M cells). Cells that cannot produce melanin are called as undifferentiated cells (U cells).

Within the first few weeks of its life, an embryo produces an activator (A) and an inhibitor (I) molecule, both of which are sent out of the cell as soon as they are produced. The activator A will tell any cell it sees, that hey, look, it is time you produced melanin. And this cell will become an M cell producing melanin.

The inhibitor I on the other hand will tell any cell it sees, look, you should not make any melanin for the time being, and this cell will remain a U cell.

Now if both A and I are present in the same environment surrounding the cell, whom should the cell listen to? Well the cell will listen to the one that is making the most noise. If there is more of A then it will produce melanin and become M cell. If there is more of I then it will not produce melanin and remain an U cell.

As both A and I are chemicals, they will diffuse through the environment. This is same as when you put sugar at the bottom of the cup and pour water on top, many hours later the water on the top is sweet because all the sugar molecules have mixed thoroughly with all the water molecules.

However, A and I are different chemicals, therefore the rate at which they diffuse is different. I moves faster than A. Therefore, the amount of A

will be closer to the cell which is producing it and there will be less and less of it as we move away from the producing cell. I, on the other hand, move faster therefore, its concentration will be less around the cell that produces it and more of it will be found further and further away.

Whether an animal will have stripes or spots is determined by the shape of the embryo. This can be best seen in case of an animal tail which at first approximation appears like tapering cylinder. James Murray, who developed much of Turing's reaction-diffusion process for biology, found through mathematical calculations that if the tail is small, then only bands will appear. If the tail is larger, then more complex patterns like spots can appear.

And this leads directly to the question of stripes versus spots and why mouse and elephants do not have any patterns. According to this model, if the embryo is very small like that of the mouse then no pattern will be formed. A slightly bigger embryo like that of the tiger and zebra will have stripes. Embryos little bigger than that of the tiger, say like that of the leopard, will be spotty in pattern. Finally huge embryos like that of the elephant will develop no pattern. So that explains why mouse and elephant have no pattern.

Does Turing's model explain everything? What role does the DNA or the genetic information play?

And finally, does it really happen? We do not have any proof that Turing's model happens in the living embryos. That awaits experimentation.

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The Thousand Eyes of the Cockroach

Of all the senses, trust only the sense of sight.

—ARISTOTLE

What is it that we see?

A human eye is a simple eye much like a camera. Light enters through a hole in the front and is focused on a light-sensitive layer in the back. The hole in the front is the pupil and the light-sensitive layer in the back is the retina. And then what happens?

When we talk of a camera, we talk of an inverted image. That is to say if a person is standing upright, the image on the camera appears as though the person is standing on her head. Is that what happens in case of the eye? Does an inverted image form on the retina?

The retina is a multi-layered structure. The outermost layer contains my favourite pigment—melanin. We have seen previously how melanin is involved in coloration. Here in the retina it does something entirely different.

But before we go further, let us just pause and ask what really is melanin.

Melanin is a protein, made of amino acids linked together by peptide bonds, just like the silk fibre or fibroin that spider makes. Of course the amino acids present in the silk fibre are completely different from those present in melanin, which is why the characteristics of fibroin are different from that of melanin.

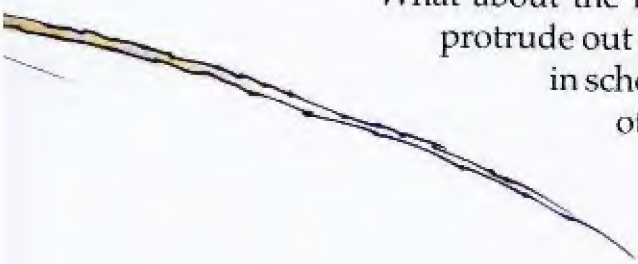
On the outermost surface of the retina, it acts like black paint. When light rays falls on a surface, some are scattered, some are reflected, and some are absorbed. Black paint reduces both scattering and reflection. And that is exactly why melanin is present in the outermost layer. It prevents light scattering and reflection so that the image that is formed is sharp and focused. There are some people who do not have this layer of melanin; such people have difficulty in visualizing under certain light conditions that normal people have no problems in.

Next to the retina is the layer of photoreceptors. These photoreceptors are also proteins known commonly as rods and cones. Rods contain rhodopsin, a form of the opsin protein that sense blue-green light in the range of 500 nm. These proteins are also very sensitive so even very dim light can be recognized by them. Cones contain cone opsins, another form of the opsin protein, which can sense the red light, the green light, and the blue light.

The nerve cells, called ganglions with long processes called

axons, are present just after the photoreceptors. Through the long axons, the ganglions connect the eye with the brain. And that is where the image is formed.

Light rays are captured by the rods and the cones; these are transformed into electrical impulses and are carried by the nerve cells up to the brain. The brain gathers all the information together, processes them, and finally prints out an image for us to see. The conversion of the electrical impulses into the image is the part we yet do not understand.



What about the immobile eyes of the insect? They protrude out from two sides and in biology class in school I learnt that the cockroaches and other insects have compound eyes. What is it that they see? Do they too see an image like we do?

Insects, including the cockroach, possess compound eyes. Each compound eye is, in reality, made of hundreds to thousands of eyes called ommatidia. Every ommatidia contains lens, crystalline cone, visual cells, and pigment cells, and is focused only one small area in space.

But what is the output? While we will not know for sure unless we become an insect, what we do know is that the insect brain processes all the information from each ommatidia to generate a mosaic picture—a pattern of dark and light dots. The greater the number of ommatidia the better the picture generated. The dragon flies for example has 28,000 ommatidia. This large number of ommatidia also enables it to span 70º horizontally and 90º vertically without moving its head—a very useful device to see the approaching prey as well as enemy.

In fact the compound eye is the ultimate motion detector. Flies not only maintain a straight course even when a gust of wind blows their way while flying but are also capable of avoiding obstacles in their way.

Werner Reichardt and Bernard Hassenstein showed that motion is detected through elementary motion detector. Simply put, neurons present in their visual system analyze the signals coming from two ommatidia scanning the same visual field. The signal coming from one ommatidia is compared to the signal coming from the second ommatidia and the insect

responds to the comparison appropriately, helping them to maintain a stable flight course.

The visual system also enables bees to fly right through the centre of a hole in a window, balancing the right and the left halves; it helps them to control their flight speed, avoid collisions, and orchestrate smooth landing on to the surface of their choice. The visual system is also used for capturing preys, chasing potential mates, and to ward off territorial intruders.

In addition to all this, the honeybees use the visual system to also calculate the distance between food source and their nest, which they communicate to other nest-mates.

The technology developed by the insects is now being studied so that midget robots can be created that could navigate in battlefields, search for victims trapped in earthquake rubble, and take images of distant planets.

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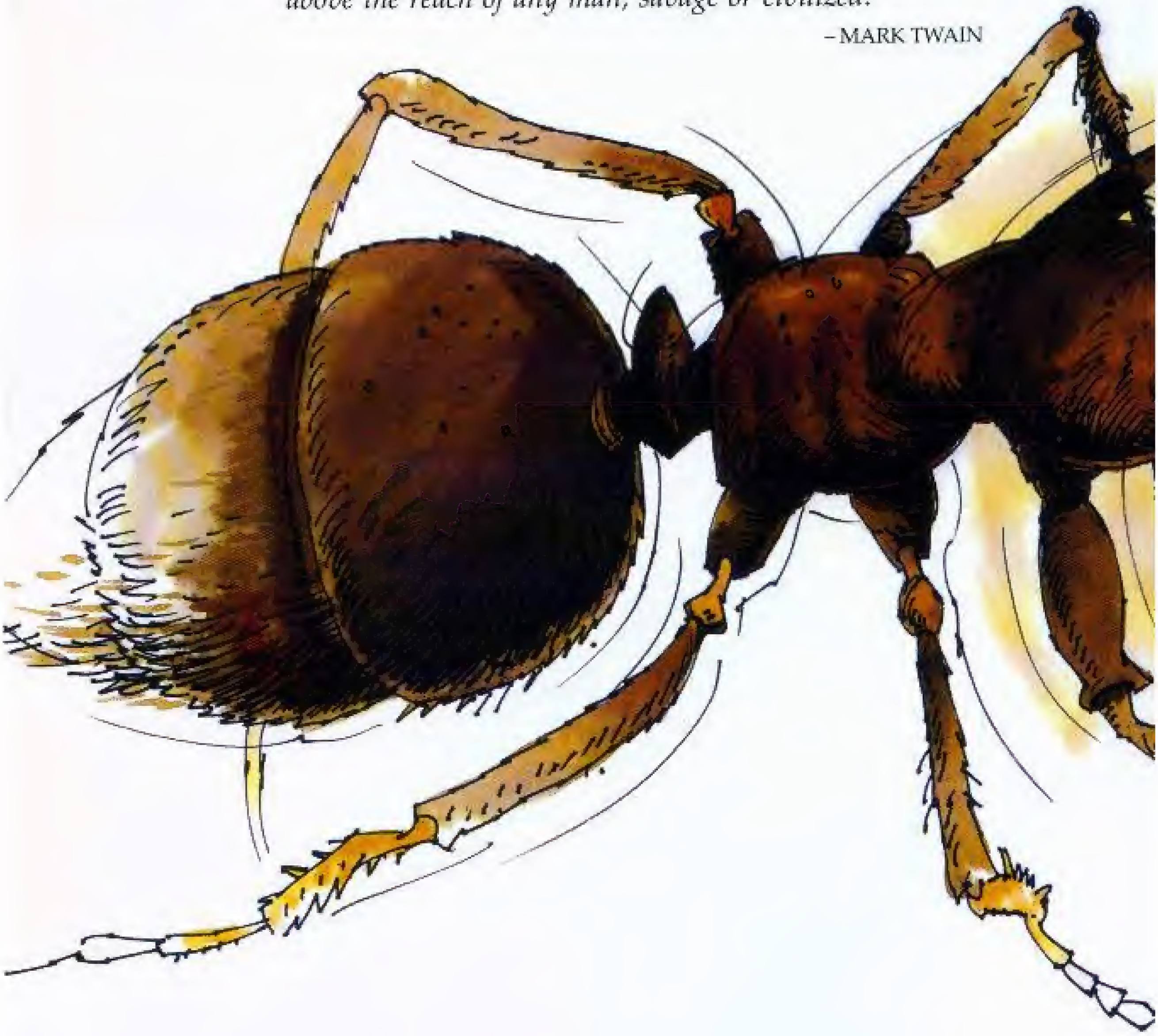
   http://www.microscopy-uk.org.uk/mag/artapr00/inseye.html

The Colony of Ants

As a thinker and planner, the ant is the equal of any savage race of men; as a self-educated specialist in several arts she is superior of any savage race of men; and in one- or two-high mental qualities she is above the reach of any man, savage or civilized!

– MARK TWAIN



In the season of the ants, a line of these tiny black-coloured creatures forms minutes within leaving food outside. Be it the sugary stuff or plain old rice grains, the ants seem to relish everything. They carry them outside, two neat little lines of ants coming and going, sometimes carrying food articles much bigger than themselves.

The neat lines fascinate me.

An ant colony starts with queen ant who lays millions of eggs at the beginning. A typical ant colony can contain few tens of individual to over a million ants living together—and this colony may contain more than one queen. The fire ants colony, for example, contains 500 queens, with up to 80,000 workers. The ant colony contains two castes: workers and reproductives. The worker ants, who are sterile females without wings, construct and repair the nest, and they feed the immature and the adult ants.

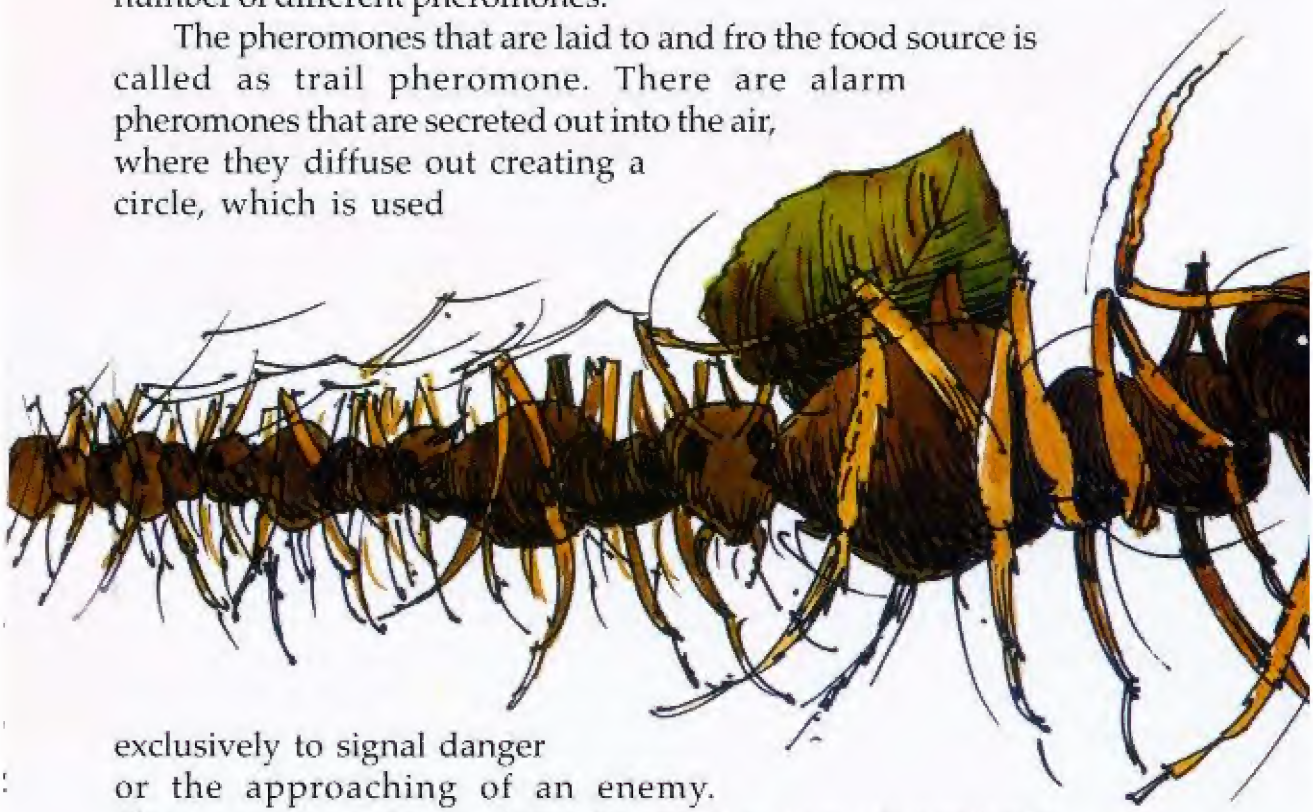
One of the classic algorithms (an algorithm is a set of mathematical formulae written to solve a problem) in computer science is called as the Travelling Salesman problem. In this problem, we have a salesman who visits clients in a number of different cities. The question now is: in what order should the salesman travel so that he covers the maximum number of cities in minimum amount of time.

For answer we look at the ant colony. In the case of ants, they too are searching for the shortest distance between the food and their nest and the same needs to be communicated to their nest-mates.

When the ant leaves her nest to forage for food, she starts leaving a trail of chemical. She does the same

when she goes back from the food source to her nest. This chemical called pheromone is secreted from a gland that is located on the posterior abdomen. Pheromones are made of unsaturated fatty acids—the same chemical group that is present in oils, fats, butter, etc. Fatty acids contain lots of carbon and hydrogen molecules. A fatty acid chain of carbon and hydrogen molecules is known as hydrocarbon chain. At one end a carboxyl molecule (-C=O) is present. All pheromones are hydrocarbon chains, but the number of carbon molecules and the way the chains are linked can differ, generating a vast number of different pheromones.

The pheromones that are laid to and fro the food source is called as trail pheromone. There are alarm pheromones that are secreted out into the air, where they diffuse out creating a circle, which is used exclusively to signal danger or the approaching of an enemy. Pheromones are also used to attract mates, to mark territories, and to tell other ants to congregate in one place.



Pheromones are secreted by many other organisms—honeybees, lizards, black-tailed deer, and mammals.

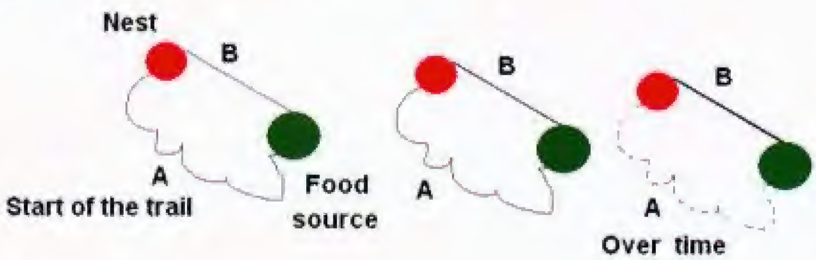
The trail pheromones laid down by the ants during foraging attract other ants to the food source. The trail is, of course, laid down only when the food source is large. If the food source is small and can be carried back to the nest by a single ant, then there is no point in laying down a trail.

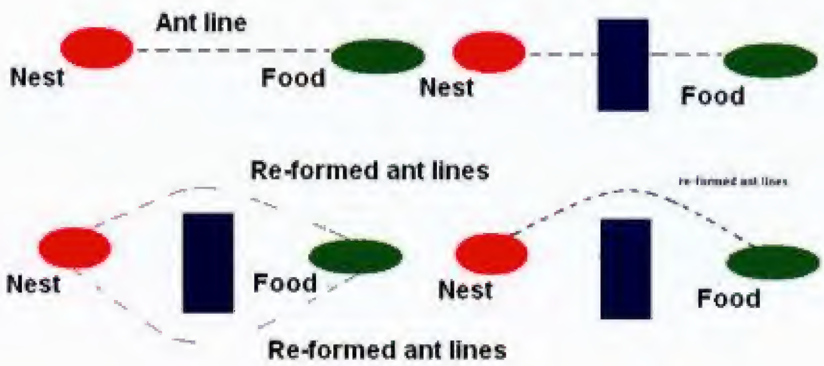
Of the many routes possible from the food source to the nest, the probability that the shortest one will be used is the maximum. The following figure best illustrates this concept.

Suppose there are two routes from the food source to the nest, called A and B, and of the two paths, A is the longer route. The ant which goes back via the shorter route, B, is going to get more chances of going back to the food source and get more food. As she goes back and forth, she is going to

secrete more and more pheromone on the B pathway, attracting more ants to this path. And each ant will secrete her own pheromone on this path making this a much used pathway than the other. Over time, therefore, the A path will be used less and less, and as pheromones evaporate rather rapidly, the trail A will disappear, leading to the usage of the shorter path by the ants.

What happens when you put in an obstacle in their path? The following figure illustrates the principle. When an obstacle is put in the path, the ants will skirt around it. Theoretically, 50% of the ants will go one way and the remaining 50% the other way. But over period of time, the path that is shortest will get a stronger pheromone trail and therefore will be used more frequently. The longer pathway will be used less and less; the pheromone as we saw in the above case will dry up and the path will be closed down in favour of the shorter pathway.





Pheromones are used to measure the surface area of the nest too. Certain ants live in crevices—small cracks in the rocks. When the nest is damaged, the queen ant sends out a scout to search for a suitable place for nesting. The scout usually makes two trips to each potential nesting place. During the first trip, which lasts just for 2 seconds, the ant lays down pheromone. In the second trip, the ant takes a different path, repeatedly crossing the first track of pheromone, slowing down when it crosses the track, till it

covers the entire surface area. From the number of crossings it makes across the first track, it calculates the surface area of the potential nest. This is somewhat similar to the method we might use when we have to measure the size of the room in the dark. We would simply count the number of steps that takes us across the room. If we need to compare the sizes of two rooms, we would then compare the number of steps. So does the ant—only it uses pheromones.

The travelling salesman and other problems of this genre are called Ant Colony Algorithm or Swarm Intelligence. A computer programme is generated using artificial ants for travelling salesman. The clients are the food source that is present in different cities. Now the programme asks the ants to search for the food and come back to the nest in the shortest possible time. The travelling salesman problem has many practical applications: planning the order in which a satellite studies a sequence of stars, drilling of circuit boards by robots, the time taken by a graphics plotter to draw a figure.

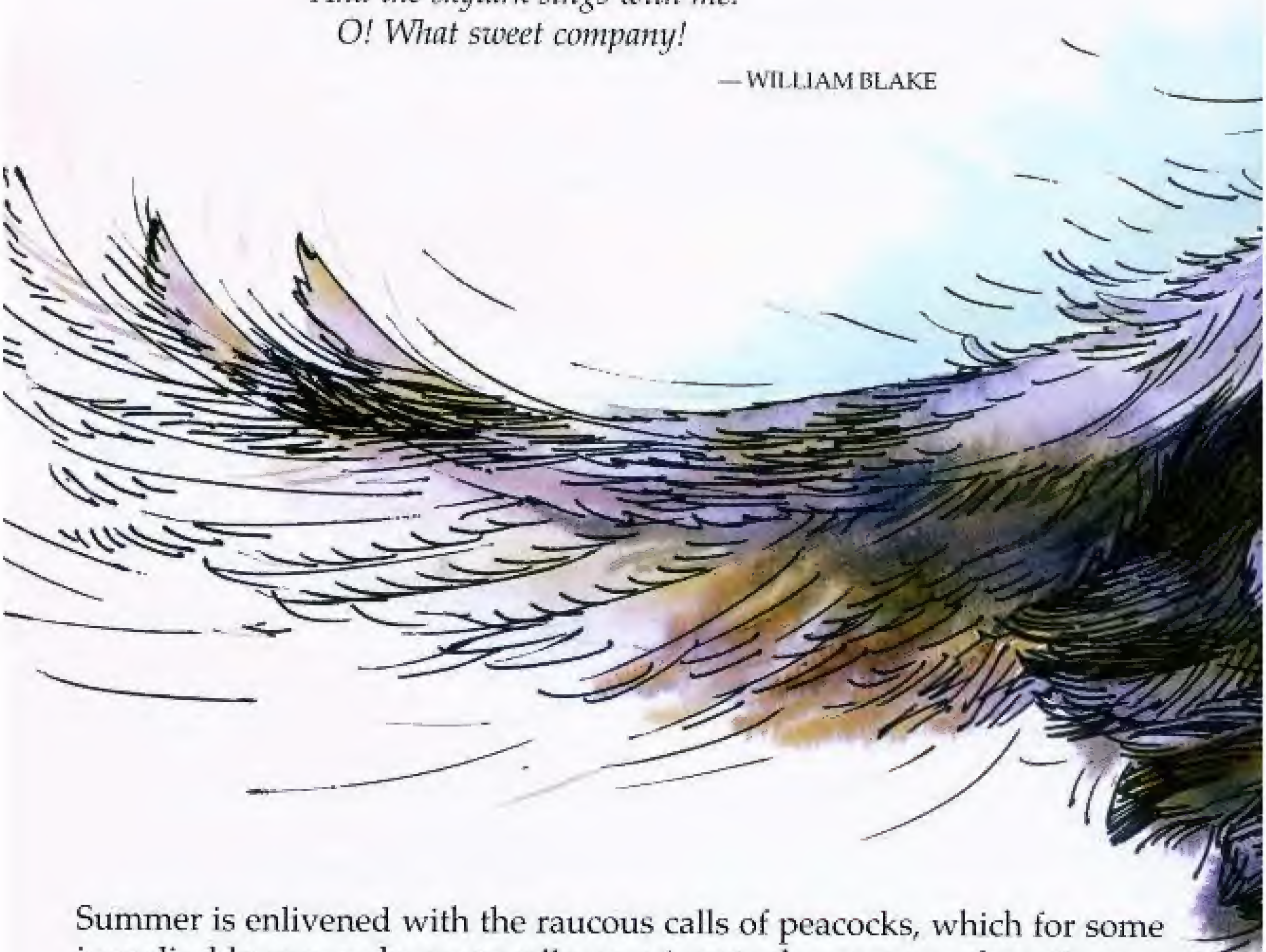
Interesting Links:

1. http://www.emporia.edu/ksn/v45n4-july1999/sect03.htm
2. http://www.frontiernet.net/~jlkeefer/ants.htm
3. http://news.bbc.co.uk/1/hi/sci/tech/1537645.stm

The Songbird of Summer

I love to rise in a summer morn
When the birds sing on every tree;
The distant huntsman winds his horn,
And the skylark sings with me.
O! What sweet company!

— WILLIAM BLAKE



Summer is enlivened with the raucous calls of peacocks, which for some inexplicable reason choose to call out at 4 am in the morning, the seductive calls of the *koel*, the soft *guttero-goo* of the *kabutars*, and the chattering of the seven sisters.

Of all the vertebrates, birds possess the greatest of all sound-producing ability. Unlike the humans, who use the larynx present in the upper regions of the trachea, the birds use the syrinx which is present lower down in the trachea where it splits into two bronchi. The syrinx contains two flaps of

tissue called labia that are present in the outer and the inner sides of the bronchial passages. As the birds force air through the syrinx, sound emanates. By controlling the air pressure in the syrinx and the stiffness of the labia the birds can change their tunes. The stiffness of the labia is controlled by tiny muscles. The more the number of the muscles, greater its ability for vocalization. All birds do not possess syrinx. The most notable exceptions are the vultures, ostriches, and mute swan.

There are two types of sounds that the birds make. One is called as calls, which may be heard through the year. These are usually short bursts of sounds, which are made either as alarm calls to warn of approaching danger, or as threat calls to tell the other birds to keep off their territory.

The second type of sound is called as songs and these are heard only during a particular time of the

year. Songs can vary; birds have been known to have dialects, same as we have. In some cases birds even have songs that are very individualistic; individuals of same species of birds will have different songs. Songs are used as mating calls, for strengthening the pair bond, and for establishing and defending nesting territory. Harsh as it sounds to us the peacock call is in reality a mating call. Often times it is only the male bird that will possess the ability to sing. Thus, the seductive coo of the *koel* is made by the male bird calling out to the female; the female bird has a much harsher call.

Neurobiologists have found that there is a specific region in the bird brain that controls the song production. This region, studied in Zebra finches that are native to Australia, is much bigger in the male birds as compared to the one present in the female birds.

The neurological model proposed by the scientists suggests that each bird is born with a neurological idea of what its song should sound like. Once the bird is born, it hones its skill by matching the sounds it hears from its father and other male neighbours to the one it has been genetically programmed to sing, some thing akin to the way a child learns to speak from listening to the adults around it.

There is much more similarity in the way sound is learnt between the birds and the humans than we thought previously. Both birds and we share a gene that is necessary for making speech.

A gene is a structural unit of the hereditary material, DNA. Deoxyribo Nucleic Acid (DNA) is made of four different kinds of chemical blocks known as adenine (A), guanine (G), cytosine (C), and thymine (T). These four chemicals form the alphabet of hereditary material. A gene is a repeat of A,G,C, and T such that the repeat holds some information, much like the way a word is formed by placing certain alphabets together in a certain fashion. For example if you place O before N, it becomes ON. But if you reverse the order, the word becomes NO with a completely different

meaning. So it is with the alphabets of hereditary. A gene thus is a string of alphabets put together in a certain order. A gene can contain up to thousands to tens of thousands of these four basic alphabets. The information that is present in the gene has to be decoded; the decoding process leads to the formation of proteins, which in turn is made of amino acids as we have seen previously.

What the neurobiologists have found out is that there is a gene present in human beings that makes a particular protein that is needed for producing language. If the protein is not present, then that person has difficulty in controlling the movements in the lower half of his/her face making it harder for them to produce certain sounds of their language.

When scientists compared the DNA from humans and birds they found that both of them contain this particular gene called FOXP2. But is this present in dogs and cats? After all they too can make sounds. Ah! But there is a difference between dogs and cats, and us and birds. While we can learn new languages, and birds can learn new songs, neither dogs nor cats can learn to bark or meow in a different way other than what they already know. Thus, neither dogs nor cats are learners, while both birds and we are classified as learners. And the gene FOXP2 makes a protein that is needed for learning a new song or a new language.

How does the protein help in learning a new song? Why is it needed? What does it really do? That will be answered only by future research.

Interesting Links:

1. http://www.garden-birds.co.uk/information/birdsong.htm
2. http://news.nationalgeographic.com/news/2001/10/1004_TVlanguagegene.html
3. http://www.dnaftb.org./dnaftb/

The Lizard's Tail

Truth is like a lizard's tail, once you grab it by tail
it breaks off and a new one grows.

—QUOTATION

It was a gruesome sight. A lizard had got trapped in between the window space and the fan of the air cooler. As I hurriedly switched off the fan, the lizard scampered off minus the tail, normal in all other respects.

Many species of lizards autotomize their tail on encounter with a predator. The tail continues to thrash about after autotomization, fooling the predator while the lizard escapes off. The breakage does not happen between the tail bones; rather there is an area of weakness within the tail bones which comes off voluntarily when there is muscular contraction as when the tail is pulled. Once the tail is pulled, muscles called sphincter muscles close the artery that supplies blood to the tail so that there is not excessive bleeding. A new tail grows back some time later in a process called regeneration. The new tail is not exactly same as the old one. There are differences in the structure and the new tail might not be exact coloration as the old one. Lizards also have to spend some energy and time in renewing the tail; this might be especially problematic if the breakage happened when food supply was low, the reason being that they store fat in their tail. But as an escape route when caught by a predator it works excellently.

Do any other vertebrates possess the regeneration ability?

Almost all animals can regenerate lost tissues to a certain extent. Lost skin grows back. Liver can be regenerated. But what about our limbs?

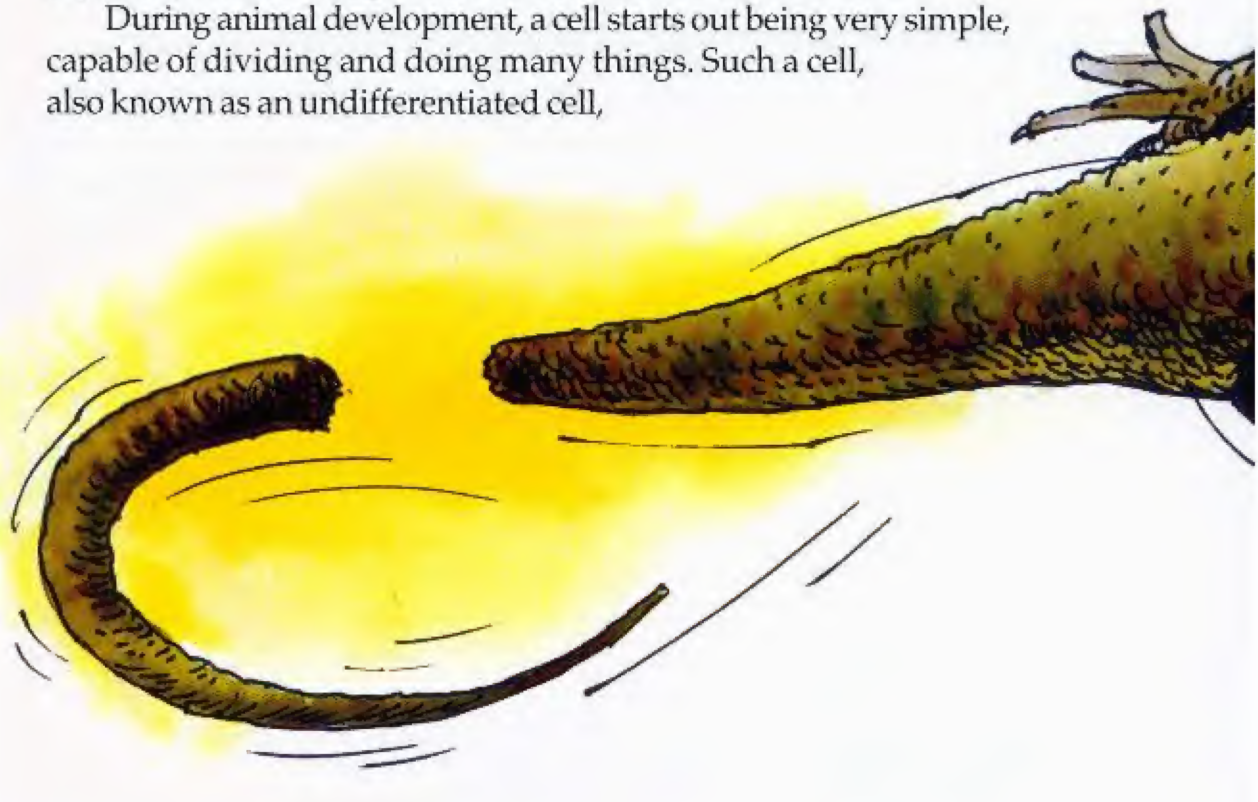
Tailed amphibians, like Newts and Salamandars, possess a tail and four limbs which they use for walking on the land. Like the frogs they can live in water too but do not possess any vocalizations. There is one more difference between them and the frogs, which are also amphibians but without a tail.

And this difference is to do with what happens when they lose a limb. Tailed amphibians can regenerate their lost limb but frogs cannot.

Why so much difference between frogs and Salamandars when both are amphibians?

Most of the cells in an organism's body are specialized. For example the heart muscle cells will work only in the heart and only the blood cells can transport blood. The process by which a simple cell (a cell contains DNA, the genetic material, proteins and other things that are necessary for it to survive) becomes specialized so that it does only one thing through its life is called as differentiation. A differentiated cell will make certain proteins that are absolutely special to that cell and no other cell, especially not the simple cell we start out with, can make.

During animal development, a cell starts out being very simple, capable of dividing and doing many things. Such a cell, also known as an undifferentiated cell,



has a certain set of proteins that are crucial for the cell's function. As the embryo grows, some cells become differentiated. Most of the proteins that were made by the undifferentiated cell stop being made and the unique

proteins are now made that impart character to the cell. Thus, blood cells, or heart cells, or liver cells, are generated from one single cell.

When Salamandars lose their limb certain very unique events happen. One of the events that happen is that the differentiated cells lose their complexity and go back to being much simpler things, capable of doing lots of different things. This process of going back in time is called as dedifferentiation. In a sense, these cells put back the clock going back in time to the state they once were in. One of the most important processes that these simpler cells can do is to differentiate back into complex cells and thus regenerate the lost limb.

The process of regenerating the limb starts immediately after the loss of that particular limb. The wound is healed at the site of the missing limb. Dedifferentiation of bone, skin cells, and red blood cells occurs in

which they lose their specialized function. The resulting clump of cells is known as blastema. Blastema eventually forms the limb bud and the whole limb is regenerated.

But why cannot cells in human beings dedifferentiate? Why when we lose a leg do we have to depend on an artificial leg?

Scientists have begun to look at this question very carefully. It so happens that to put the clock back in time, certain genes have to be switched on and certain genes have to be switched off. Those genes which make proteins that are unique to the differentiated cells have to be told to stop making those proteins. This process is known as gene switching off. Other genes whose proteins were necessary in the undifferentiated cells are told to switch on so that these proteins are made in abundant quantity.

One of the genes that are needed by the undifferentiated cells is known

as Wnt. This gene is generally switched off once the cell becomes differentiated. Therefore, when the cell dedifferentiates, it has to be switched on again.

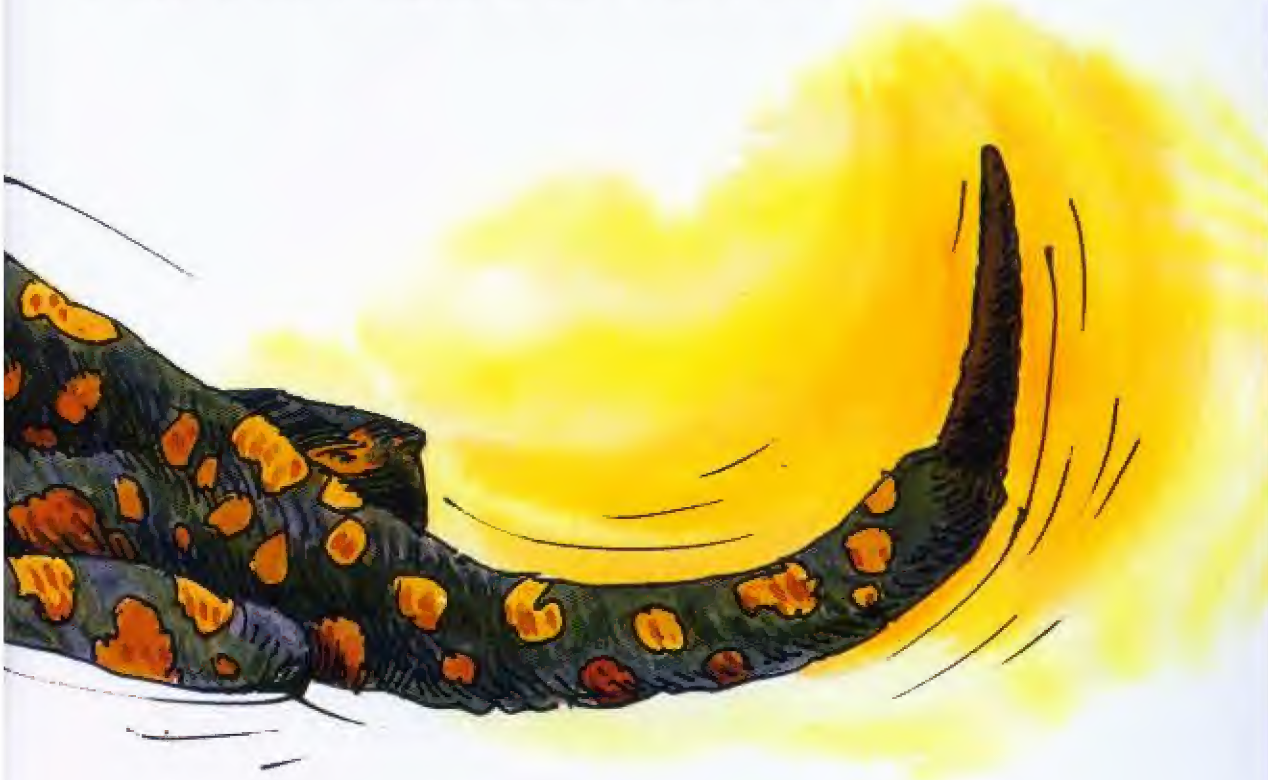
Somehow in Salamandars this happens upon limb amputation. And it does not happen in frogs and in human beings. Which is why in Salamandar limbs regenerate back but in humans and frogs it does not.

Why does Wnt switch on in Salamandars but not in humans?

Ah! If only we could figure that out!

Interesting Links:

1. http://www.ubuntu.fm/2010/11/lizards-tail/
2. http://www.luc.edu/depts/biology/dev/regen2.htm
3. http://www.sciencemag.org/cgi/content/full/276/5309/81#F1



Do Elephants Forget?

Elephants never forget.

— *PROVERB*

I love to read the comic strip Calvin and Hobbes. Calvin is six years old with a tiger toy whom he calls as Hobbes and with whom he has many adventures. In one of the events, Calvin has to memorize words for his English teacher. He sits at his desk in his room poring at his book, while he would so obviously like to be outside playing with his tiger pal. Then he has a brain wave! Of course, he says, I will transmogrify into an elephant for everyone knows elephants have amazing memory and all I have to do is to look at the book once and lo, I would have remembered all the words. And then follows his adventure as he pretends to turn himself into an elephant.

But what really is memory? How is it generated? Where is it stored? In what form is it stored?

Brain is a mass of cells called nerve cells or neurons. These cells are very, very different from other cells. For one thing they have long processes called axons, which help one neuron to communicate with another neuron. These axons transmit electrical impulses in the form of positive and negative ions from one neuron to another neuron and as electrical impulse travels, information is processed. Our brain contains 100 billion neurons.

When an event happens, or when we meet someone, or when we learn something, the brain determines whether it is worth storing. If it decides

that it needs to be stored then it becomes memory. In fact, what the brain does and what the computer does are similar. In the computer, you have a hard disk where all the data is stored. There are parts of brain known as cerebral cortex which stores information or data.

The ability to form memories is found in the simplest of animal to the most complex of them. Thus, memories are formed in honeybees and snails, and they are formed in elephants and humans.

There are three parts to memory:

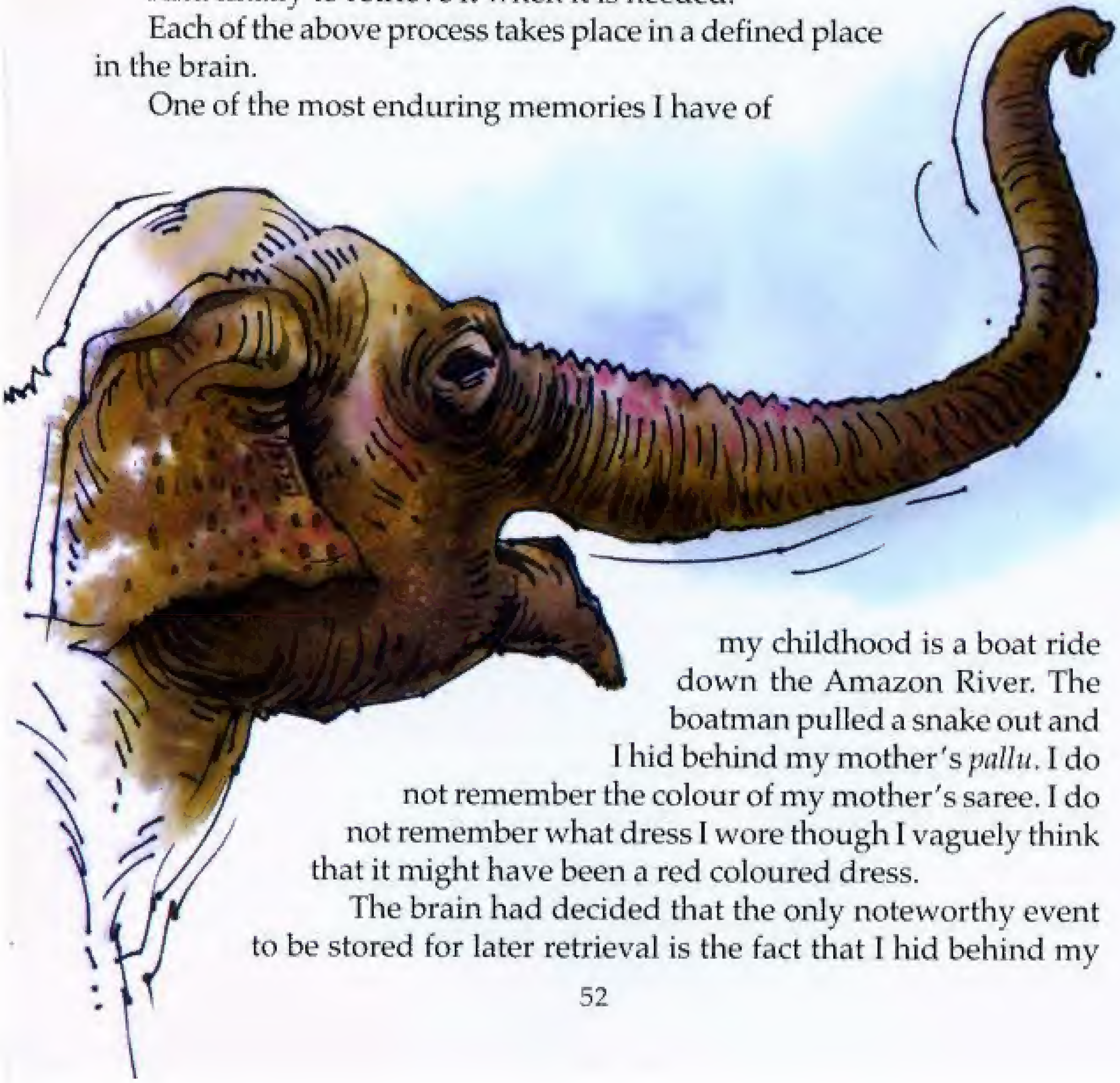
To recognize that something is worth storing

To store it appropriately

And finally to retrieve it when it is needed.

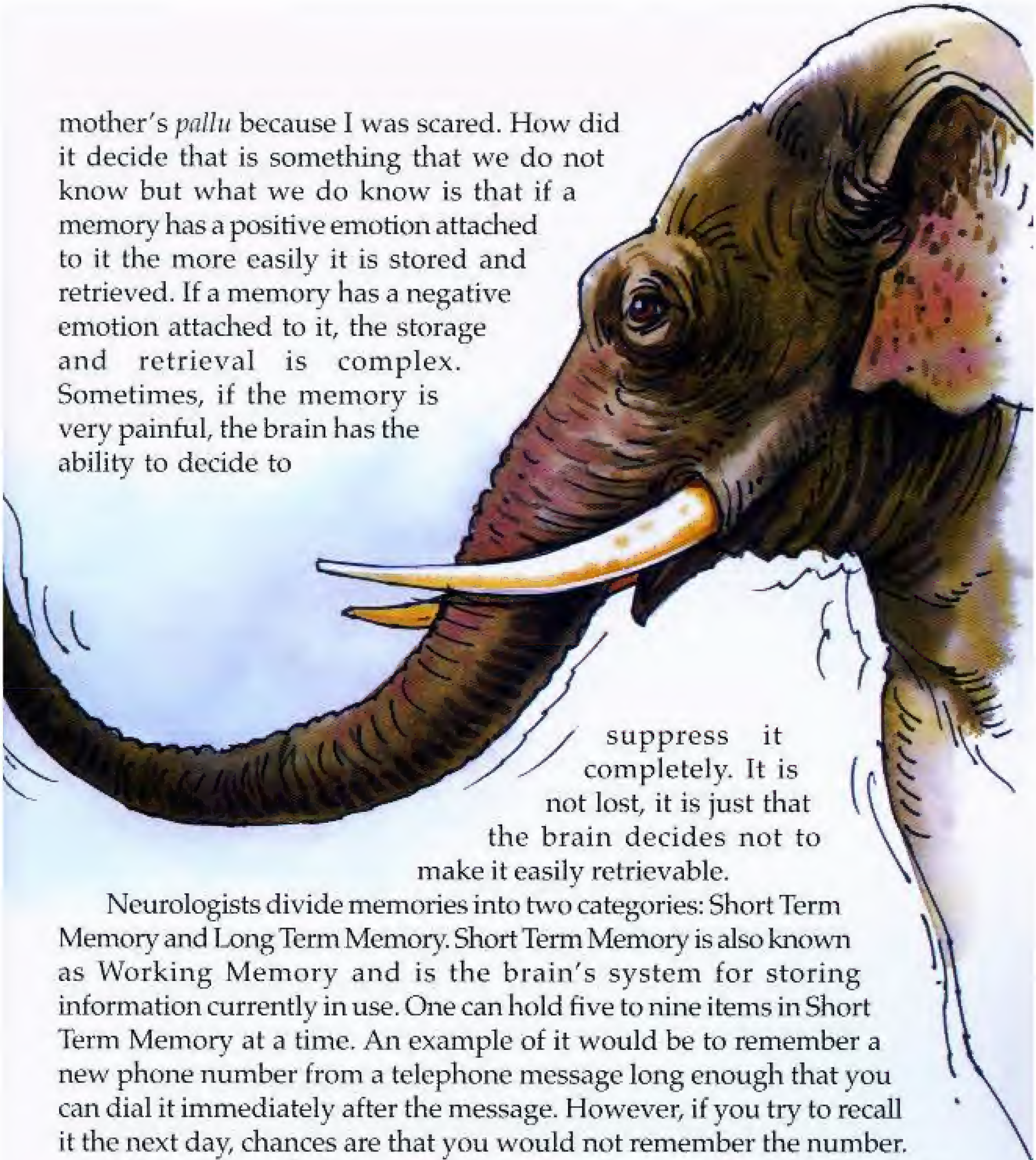
Each of the above process takes place in a defined place in the brain.

One of the most enduring memories I have of



my childhood is a boat ride down the Amazon River. The boatman pulled a snake out and I hid behind my mother's *pallu*. I do not remember the colour of my mother's saree. I do not remember what dress I wore though I vaguely think that it might have been a red coloured dress.

The brain had decided that the only noteworthy event to be stored for later retrieval is the fact that I hid behind my



mother's *pallu* because I was scared. How did it decide that is something that we do not know but what we do know is that if a memory has a positive emotion attached to it the more easily it is stored and retrieved. If a memory has a negative emotion attached to it, the storage and retrieval is complex. Sometimes, if the memory is very painful, the brain has the ability to decide to suppress it completely. It is not lost, it is just that the brain decides not to make it easily retrievable.

Neurologists divide memories into two categories: Short Term Memory and Long Term Memory. Short Term Memory is also known as Working Memory and is the brain's system for storing information currently in use. One can hold five to nine items in Short Term Memory at a time. An example of it would be to remember a new phone number from a telephone message long enough that you can dial it immediately after the message. However, if you try to recall it the next day, chances are that you would not remember the number.

The memory that I described earlier is an example of Long Term Memory, the ability of brain to store information of unlimited capacity over an extended time. Scientists speculate that a region of brain known as hippocampus, so called because it looks like a sea horse, might be involved in the generation of this type of memory. During Long Term Memory

generation the neurons gain the ability to transmit much stronger electrical impulse than they are normally capable. After generation, the memory is transmitted to Cerebral Cortex, where it is stored.

The physical mechanisms making memory remain little understood. One of the hypotheses that scientists have advanced is that a protein might be involved in making memory. Researchers working at National Institutes of Health, USA, have discovered a protein they call as mature Brain-Derived Neurotrophic Factor (mBDNF) that appears to be absolutely important for generation of Long Term Memory. The protein changes the chemical atmosphere of the neuron so that it can now transmit the much stronger electrical impulse required for creating Long Term Memory.

Memory loss is associated with Alzheimer's disease in human beings. The disease was first described by Alois Alzheimer in 1906. In this disease, recently Ronald Regan, former president of United States of America died of Alzheimer's disease, protein molecules called Prions destroy the nerve cells especially in the cerebral cortex, which we know is needed for storage of memory, and the hippocampus, which is needed for making Long Term Memory, and with it they destroy the memory storage in the brain. Ultimately the person remembers nothing—his name, how to tie the shoe lace, how to walk, how to eat.

Finally, to come back to the proverb 'Elephants never forget', there appears to be some truth in the old proverb. The elephant herd consists of a matriarch, the oldest and the most dominant female elephant, and 10-20 other elephants that can include her sisters, cousins, daughters, and their young offspring. It is now known that the dominant female of the herd builds up a social memory enabling her to recognize 'friendly faces' and warn the herd if an unfriendly face appears.

Interesting Links:

1. http://serendip.brynmawr.edu/biology/b103/f97/projects 97/Warren.html
2. http://www.memoryzine.com/howmemoriesaremadein brain.html
3. http://www.news-medical.net/?id=5607
4. http://normandy.sandhills.cc.nc.us/psy150/nervsys.html
5. http://faculty.washington.edu/chudler/alz.html

Territorial Wars

Find out thy brother, wheresoe'er he is;
Seek him with candle; bring him, dead or living,
Within this twelve month, or turn thou no more
To seek a living in our territory.
Thy lands and all things that thou dost call thine
Worth seizure, do we seize into our hands.

—SHAKESPEARE

"WOOF"

"WOOF! WOOF"

"ARF! ARF! ARF!"

"WOOF"

And so it went on. There were three dogs on one side and four on the other side. There was an invisible boundary neither set was willing to cross, and they were barking at the top of the voice.

"ARF! WOOF!"

"WOOF! WOOF!"

I was a witness to a territorial war between the two groups of dogs.

Dogs were domesticated some 12,000 years ago. Around that time somewhere near Israel, a man was placed in a grave with his hand cradling a puppy. Whether that puppy was a dog or a wolf is not known for sure; what we do know is that the wolf and the dog have identical DNA, the piece of molecule that contains all the genetic information of an organism.

Both dog and wolf are placed under Canid family of order Carnivora. Both wolf and dog exhibit similar characteristics, of which one is the propensity to live as packs.

A wolf pack consists of 6-7 animals; a set of parents and generations of their offspring. The packs define a territory wherein they live and feed and

which they protect from incursions from other packs.

The territory is marked by wolves by urinating near the edges and on tree stumps, rocks, or logs that are present in their territory. The size of the territory depends on many variables including abundance of food, accessibility to refuge, and other social factors. It is a behaviour that involves many strategies and many decision making events.

Many animals, including tigers, primates like Chimpanzees, birds such as yellow-headed black-birds, decided to be territorial. Yet there are others, like giraffes and Swamp Deer (*barasingha*), which are not territorial.

The benefits of a territory are obvious: there is lower risk of predation, food is available, and it provides a better environment for raising the young.

The cost of territory is that the animal(s) need to get one and maintain it, which implies that they have to spend some time in defending it.

An animal, therefore, basically has to make two decisions: i) whether

to be territorial, that is, whether they should have a territory to roam in; ii) if they decide to have territory, then what size should it be so that they can comfortably defend it.

The strategies and decisions can be mathematically defined as was explained by John Nash, a mathematician at Princeton University, who later got Nobel Prize for this work. The definition, called Game Theory, has been used by economists and other scientist to explain rational behaviour and how far human depart from pure rationality.

Game Theory was adapted to explain the territorial behaviour exhibited by animals by Maynard Smith. Using the military terms of Hawk and Dove, he sought to explain the territorial behaviour observed in animals.

Hawks are fighters. They will fight for resources like food. The upside

of the fight is that they get the food. But there is a price they have to pay. Fighting can result in injuries or in extreme cases they can be killed.

Doves are peace-loving creatures. They do not like to fight for resources. They will contend themselves by displaying by aggressive behaviour but

will not go all out and have a fight. The upside is that they will not get injured or get killed. But the price that they have to pay is that they will also not get the food.

Should animals fight in territorial disputes?

Let us analyze the following situation mathematically:

If the winner gets the territory, he gets 50 points

The loser loses the territory, and gets 0 points

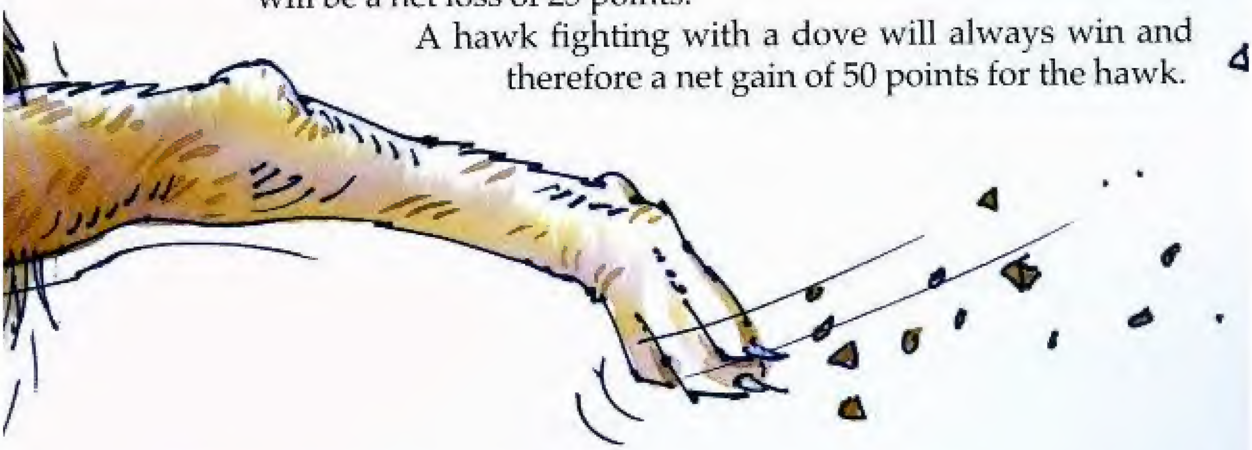
An injury during war results in losing 100 points

A display as a dove does will result in losing 10 points.

OPPONENT (→) ATTACKER (↓)	HAWK	DOVE
HAWK	0.5 (50) + 0.5 (-100) = -25	+ 50
DOVE	0	0.5 (50-10) + 0.5 (-10) = +25

If a hawk fights with a hawk, each hawk has 50 per cent of winning and gains 50 points. The other hawk, the loser, will lose 100 points. There will be a net loss of 25 points.

A hawk fighting with a dove will always win and therefore a net gain of 50 points for the hawk.



A dove will never attack a hawk and therefore not gain the territory and therefore will be a loser.

A dove fighting with a dove will be contented with lots of display for which it has to pay the penalty of 10 points. Each dove again has a 50 per cent chance of winning; but winner has to pay the penalty of 10 points

because it has won through display. There will be a net gain of 25 points.

But a population can never be pure!

A population can never be pure hawk for they will be fighting all the time. Neither can it be pure dove for even if one hawk enters the population, the doves will lose. Therefore, there is always a mix of hawk and dove in the population.

Now to the hawk-dove game, let us add a third component—bourgeois. The dictionary meaning of bourgeois is:

Bourgeois:

1. A person of middle-class
2. A member of the property owning class

Therefore, an animal who has territory is a bourgeois. This animal will behave like a hawk. It will defend its territory. It is its right, its castle and it does not want to lose it. But it will not go out like a hawk seeking fights. In that aspect it is like a dove, it prefers to be let alone to live in its castle. This animal, thus, is neither pure hawk nor pure dove. It will win more encounters than the pure doves, and will avoid more damaging encounters than the pure hawks.

And that is what happens in a territorial war. An animal which has defined its territory will try to defend it from intruders. If it finds another animal of its own entering its region, it will fight, just like the two sets of dogs were doing.

The noise level was now coming down. Soon there was just a miffle, a half-hearted bark, and then the two packs dispersed. The war over the territory was over.

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2. http://www.pnas.org/misc/classics5.shtml
3. http://www.kids.net.au/encyclopedia-wiki/ga/Game_theory
4. http://www.kids.net.au/encyclopedia-wiki/jo/John_Maynard_Smith
5. http://www.discoverchimpanzees.org/

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